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Integration of Wind Generation Potential in the State of Rio Grande do Sul, Brazil – A Prospective Study

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SUMMARY
The state of Rio Grande do Sul, located in the southernmost part of Brazil, is one of the Brazilian states that have the highest onshore wind resource potentials in the country. According to the new wind resource map, published by Rio Grande do Sul State Government, the wind resource potential estimates can exceed 100GW considering the annual average wind speeds around 7m/s at 100 meters high.

The wind resources are distributed over several different regions in the state, however, the coastal area concentrates over 70% of all the estimated onshore potential and over 85% of all the existing wind farms. Nowadays, the state’s installed capacity is just about 600MW. Nonetheless, with the advent of the PPA (Power Purchase Agreement) Auctions, that stimulated the expansion of alternative energy sources in Brazil, the installed capacity of the state of Rio Grande do Sul is going to increase substantially, reaching 1.4GW by 2015, and tends to increase even more in the future.

In order to integrate the contracted wind farms to the system and allow the connection of future power plants, EPE has made a prospective study that focus on establishing an optimized grid expansion that is capable of allowing the connection of wind farms in the most promising regions. This study considers that the wind farms that have registered at EPE to participate in the PPA Auctions since 2009 will be gradually installed in all different regions of the state, reaching approximately 9GW by 2023.

In this paper, the results of this long-term study are presented, providing the reader a broad approach to all the technical challenges that are related to the integration of large wind power potentials in Brazil.

KEYWORDS

Transmission Planning, Wind Generation, Wind Power Integration

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1. INTRODUCTION

The Brazilian wind potential has been the subject of studies and inventories since the 1970s. In 2001, the "Brazilian Wind Potential Atlas" was published by CEPEL, and it is considered the first work that has presented data for survey of wind power in Brazil. Figure 1 below shows some of the estimates on the onshore wind power potential presented in the Wind Potential Atlas.

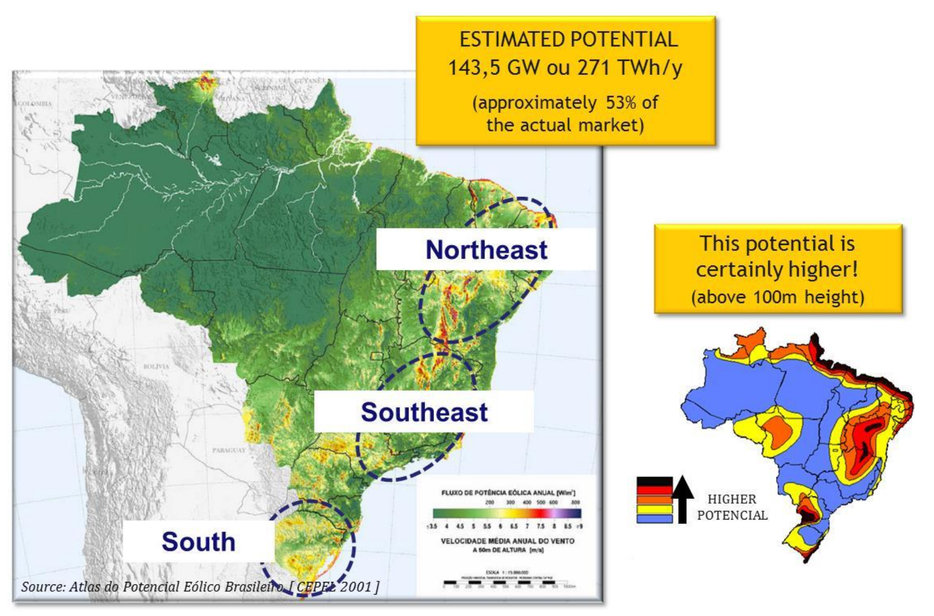


Figure 1 Brazilian Wind Power Atlas.

The Brazilian wind power potential estimated in this Wind Atlas, and presented on Figure 1, was obtained by considering annual average wind speeds around 6m/s at 50 meters high. Since wind turbines are now available with hub heights up to 150m, and 100m towers are becoming the new standard, the actual wind power potential is certainly much higher than the one that has been published by CEPEL in 2001 [1].

Actually, the State Governments of the Brazilian states that have the best land based wind sites have shown interest in stimulating the wind industry. So, besides providing some favorable energy policies, they have started updating their wind resource maps taking into account the latest technologies available.

Under this context, the Rio Grande do Sul State Government has published an updated wind resource map [2] focusing solely on the state's wind power potential. This map indicates that state's wind resource potential can exceed 100GW if annual average wind speeds around 7m/s at 100 meters high are taken into account. Besides, it has identified six different regions where the wind power potential is more promising.

Figure 1 below show the state's most promising regions for wind energy exploitation.

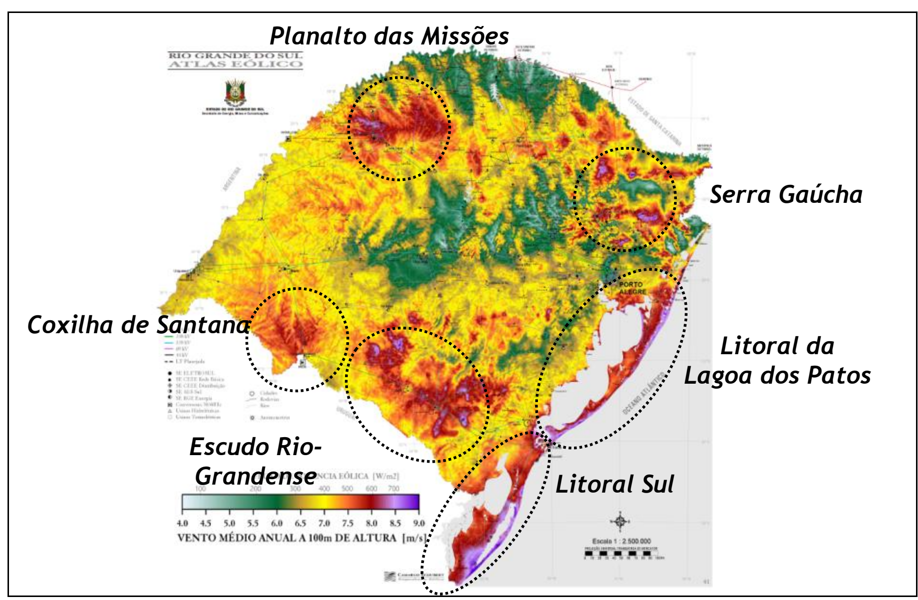


Figure 2 Rio Grande do Sul Wind Power Atlas.

It is also important to mention that although six regions were identified, the southernmost regions of the state (Coxilha de Santana and Escudo Rio Grandense) and the coastal areas (Litoral Sul and Litoral da Lagoa dos Patos) concentrate the highest potentials in the state.

Nowadays, the majority of the existing wind power plant projects is installed or under construction in the Lagoa dos Patos and Coxilha de Santana regions. This characteristic is related to the more favorable wind regimes of these areas as well as the advantageous locations for the access to the transmission system.

These conditions have affected positively the results of the Power Purchase Agreement (PPA) Energy Auctions run by the Federal Government since 2009. From 2009 to 2012, seven PPA Energy Auctions were run, and 49 wind farms (1116MW) were contracted only in Rio Grande do Sul state, making the its installed capacity increase substantially, from 230MW, in 2008, to 1.4GW by the end of next year.

Table 1 below shows the number of projects registered in the state of Rio Grande do Sul to participate in the PPA Auctions as well as their the installed capacity of the contracted projects from 2009 to 2012.

Table 1 Registered Projects and Contracted wind farms.

Region	Number of Registered Projects	Installed Capacity of Registered Projects (MW)	Contracted Installed Capacity (MW)	Known potential (MW)
Coxilha de Santana	58	1397	180	1577
Litoral Sul	98	2130	402	2532
Escudo Rio Grandense	26	709	0	709
Lagoa dos Patos	135	3648	534	4182
TOTAL	***317***	***7884***	***1116***	***9000***

As can be seen in Table 1, there are more than three hundred projects registered to participate in the PPA Auctions in the state of Rio Grande do Sul. The installed capacity of these projects exceeds 7GW and, by analyzing the wind farm projects, it is possible to check that most of them are located in areas where the grid still has some remaining transmission capacity.

This remaining capacity, however, tends to be used completely in the following years depending on the results of the PPA Auctions. Therefore, the transmission system capacity will become a limiting factor for the integration of future power plants in the state of Rio Grande do Sul if no reinforcements are planned.

In order to cope with this generation expansion, EPE has developed some specific transmission expansion studies, called “Prospective Studies”, that consider a prospective and incremental increase in the wind installed capacity of the most promising regions, and focus on establishing an optimized grid expansion. These studies consider, among many other aspects, the environmental impacts of the new transmission installations and the investment costs associated to them, as well as the adequacy of the proposed expansion to the load supply needs.

2. OBJECTIVE

The main objective of this paper is to show the results of the transmission expansion studies developed by EPE to allow the integration of the Rio Grande do Sul State future wind power potential.

3. STUDY CRITERIA AND GENERATION SCENARIOS

This prospective study has adopted the most common and traditional transmission expansion planning criteria used in Brazil, and it has focused on obtaining the optimum expansion for the Rio Grande do Sul transmission system.

The most important criterion that has been used is the “N-1” security criterion, which determines that sufficient reserves must be provided throughout the system so that it can tolerate the loss of any one component at any time guaranteeing that, in any situation, the generation always meets the load.

The performed analyses were based on the Transmission Expansion Planning database provided by EPE, and it has considered the year of 2023 as the time horizon. The impacts on the transmission configuration for years 2015, 2018, and 2021 were also analyzed.

In order to define the best transmission expansion alternative, the Minimum Global Cost economic criterion (minimum sum of investment costs and power losses costs) was used.

The study scenarios were established by combining load and generation conditions representing different periods of the year. Each scenario is characterized by a combination of hydrological conditions (dry or wet season), of the availability of thermal and wind power plants, and load conditions (heavy and light load).

The scenarios that have been considered in this study are presented in Table 2 below.

Table 2 Study scenarios.

Hydrological condition/load	Scenario 1		Scenario 2		Scenario 3	
	Dispatch		Dispatch		Dispatch	
	Thermal	Wind	Thermal	Wind	Thermal	Wind
Dry season, heavy load	Minimum	0%	Minimum	100%	Maximum	100%
Wet Season, light load	Minimum	0%	Minimum	100%	Maximum	100%

The list of the existing and planned thermal and hydropower plants in the state of Rio Grande do Sul can be seen in Table 2 below.

Table 3 Existing and Planned Thermal and Hydro Power Plants.

Type	**Installed Capacity (MW)**		**TOTAL**
	Existing	**Planned**	
Thermal - Gas	160	1050	***1210***
Thermal - Coal	842	950	***1792***
Hydro	1782	152	***1934***

Also, based on the information of all projects registered to participate in the PPA Auctions, it was possible to estimate the installed capacity of wind farms that could possibly be integrated to the Brazilian grid in the future. The results of the auctions that have been run from 2009 to 2012 have also been considered. By using this information, it was possible to define the prospective generation increases and their respective shares for each region of Rio Grande do Sul for years 2015 to 2023.

The prospective increases in wind power installed capacities for each assessed area are shown in Table 4. Figure 3 below shows a schematic spatial distribution of the prospective wind power installed capacity that has been used in all simulations.

Table 4 Prospective wind generation considered in the study.

Region	**Contracted Installed Capacity (MW)**	**Prospective Installed Capacity 2015 (MW)**	**Prospective Installed Capacity 2018 (MW)**	**Prospective Installed Capacity 2021 (MW)**	**Prospective Installed Capacity 2023 (MW)**
Coxilha de Santana	180	455	823	1190	1557
Lagoa dos Patos	534	1203	2096	2988	3881
Litoral Sul	402	828	1396	1964	2532
Planalto das Missões	0	4	9	15	22
Escudo Rio-Grandense	0	142	330	519	708
Serra Gaúcha	0	60	140	220	300
TOTAL	***1116***	***2692***	***4794***	***6896***	***9000***

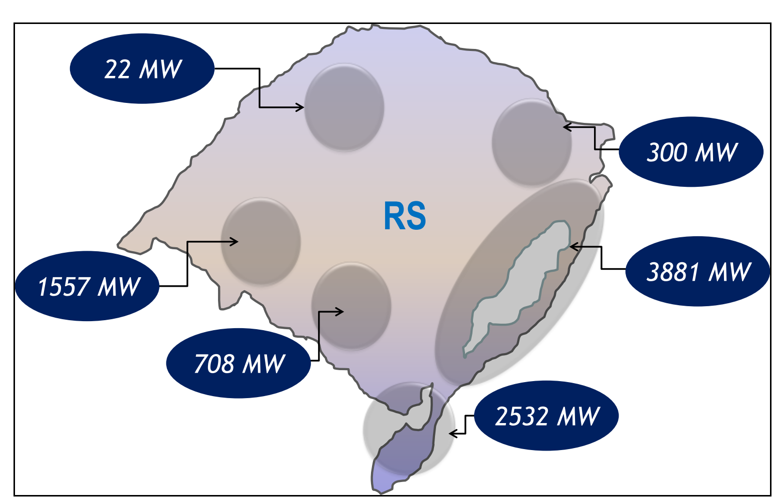


Figure 3 Prospective installed capacity considered to be integrated to the grid in 2023.

4. GRID INTEGRATION ASSESSMENT

As described in the latter sessions, the main objective of this study was to establish an optimized transmission expansion that allows the integration of 9GW of wind power to Rio Grande do Sul transmission grid.

Nowadays, the state's grid is basically composed of 230kV lines that are unable to provide enough transmission capacity to integrate this prospective potential. Furthermore, the electric behavior of the western part of the electric system, although interconnected to the rest of the grid, is almost independent from the southern and northeastern regions. This characteristic allows the performance analysis to be done in two distinct moments.

The first part of the analysis established an optimized expansion for the Planalto das Missões and Coxilha de Santana regions. The second one established the transmission expansions that are required to integrate the wind power potential located in the coastal areas.

Figure 4 shows the adopted division used to analyze the optimal transmission system expansion in the state.

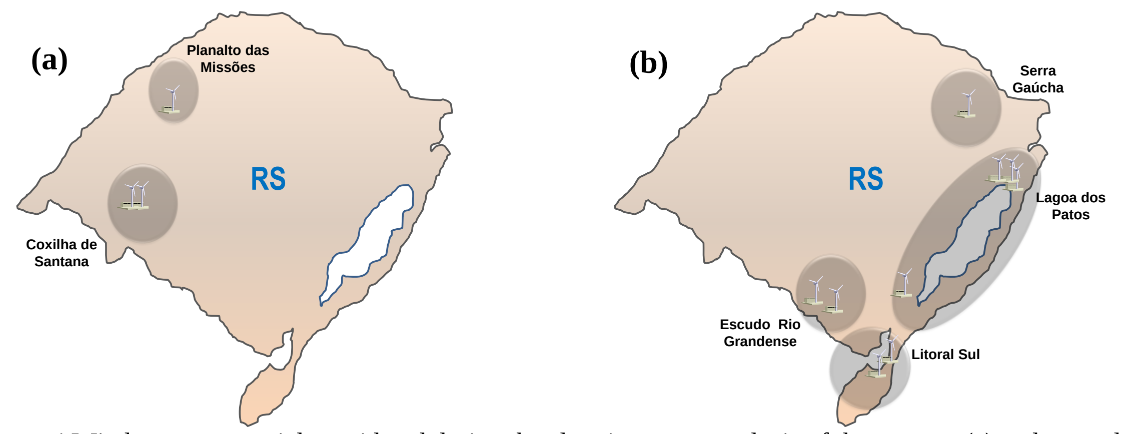


Figure 4 Wind power potential considered during the electric system analysis of the western (a) and coastal area (b) system performance.

4.1 <u>Western region transmission expansion alternatives</u>

In order to allow the integration of 1.5GW of wind power installed capacity three different transmission expansion alternatives were analyzed (see Figure 4):

1) Alternative 1 → this alternative contains a new 525/230kV (1344MVA) substation connected to the existing grid by a 525kV double circuit transmission line. The new substation is located near the wind farm sites in Coxilha de Santana region.
2) Alternative 2 → this alternative contains a new 525/230kV (1344MVA) substation connected to the existing grid by two 525kV single circuit transmission lines connecting the Coxilha de Santana region to the northwestern and southern regions of the state.
3) Alternative 3 → this alternative does not contain any expansion in the 525kV voltage level. In this case, two new 230kV substations and six new 230kV transmission lines are responsible for providing the extra transmission capacity needed.

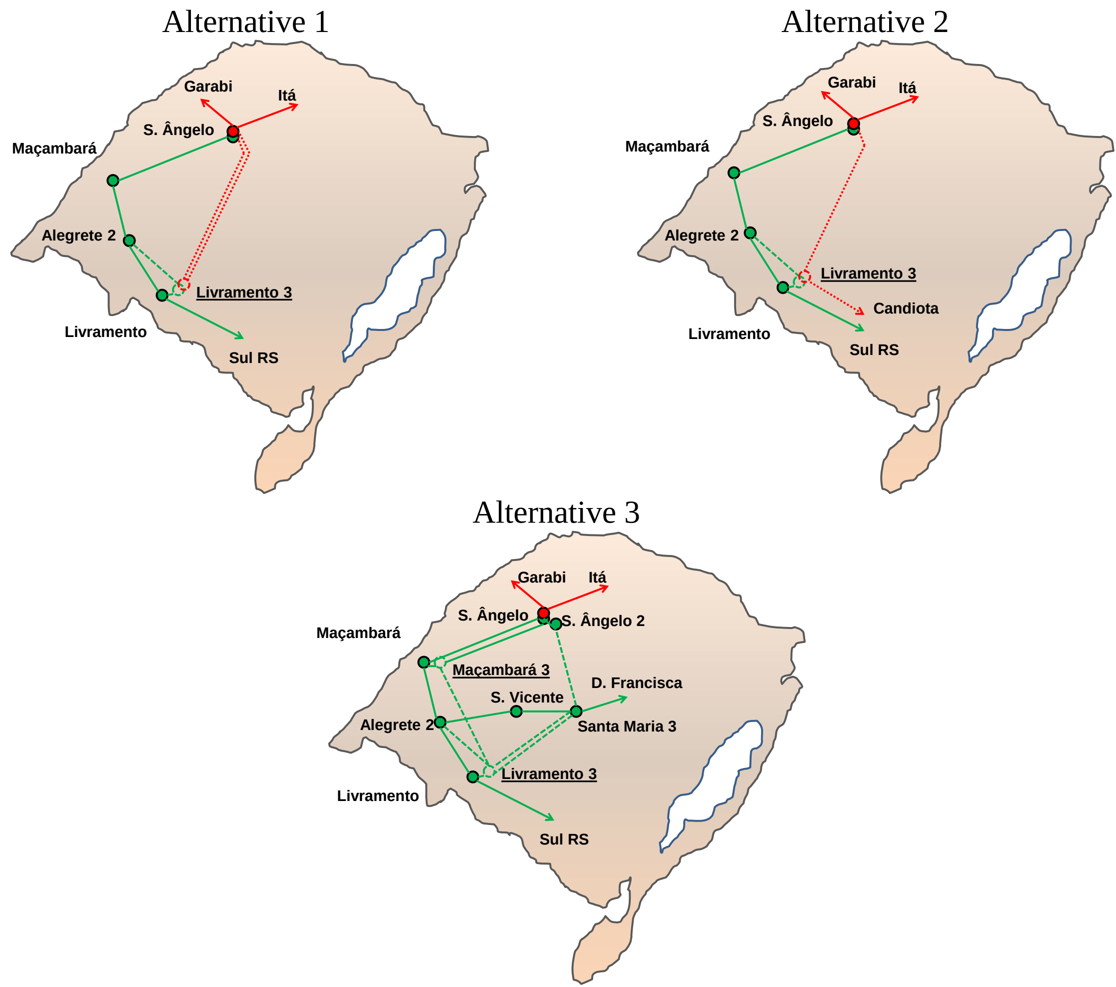


Figure 5 Alternatives considered for the transmission expansion of the western region.

The technical and economic feasibility studies of the proposed alternatives have indicated the Alternative 3, which considers the grid expansion only in 230kV voltage level, is the least expensive alternative, and the costs associated to it (see Table 5) are least 30% lower when compared to the other alternatives.

Table 5 Results of the economic feasibility analysis for the transmission expansion alternatives.

Total investment and electric losses costs			
Alternative	**Costs (R$ x 1000)**	**(%)**	**Order**
1	276.959,22	135,4%	3º
2	278.966,14	136,4%	2º
3	204.566,82	100,0%	**1º**

Table 6 below shows all the planned substations and transmission lines associated to the Alternative 3.

Table 6 Transmission lines and substations - Alternative 3.

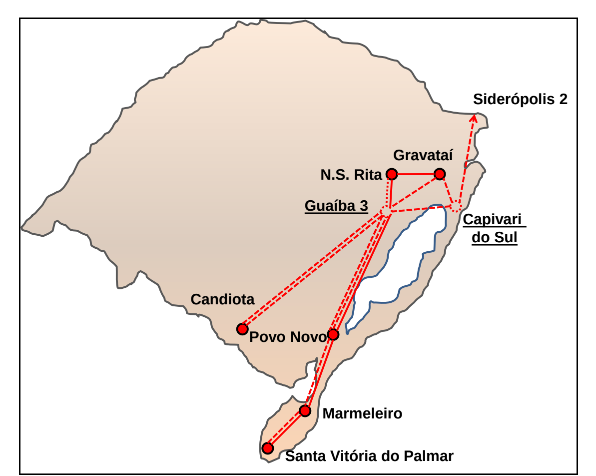
Transmission lines	Length (km)
TL 230KV Cerro Chato - Livramento 3	2
TL 230KV Livramento 3 - Santa Maria 3 C1 and C2	2 x 240
TL 230KV Livramento 3 - Alegrete 2	117
TL 230KV Livramento 3 - Maçambara 3	200
TL 230KV Santa Maria 3 - Santo Angelo 2	165
SS 230kV Livramento 3	-
SS 230kV Maçambará 3	-

4.2 Proposed transmission expansion for the coastal region

The coastal region of the state concentrates over 80% of all the prospective wind power generation assessed in this study. This region also has the majority of the state's load, which means all the proposed transmission expansion in this region should be in accordance with the load demand needs.

Since the prospective installed capacity to be integrated in this region is not compatible to transmission expansions in 230kV voltage level, only a few new transmission installations in this voltage level were assessed. Also, as most of the wind farm projects known so far are concentrated in some specific sites, no different alternatives were analyzed for this region.

Figure 6 below shows the proposed transmission expansion for the coastal area of Rio Grande do Sul.



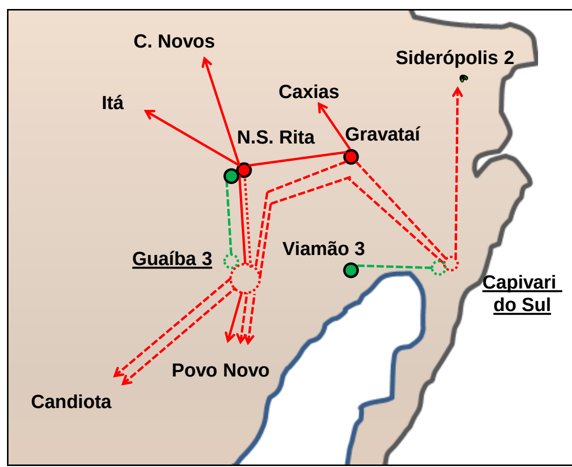


Figure 6 Alternatives considered for the transmission expansion of the western region.

It is important to mention that the proposed expansion includes two new 525/230kV substations (1344 MVA + 1344 MVA) and a set of nine 525kV transmission lines (1100 km) that are responsible for integrating the wind power potential in the whole coastal area, allowing the connection of more than 9GW of wind power. Also, the costs associated to this expansion are about 2.5 billion reais.

Table 7 New Transmission lines and substations recommended for the coastal area.

Transmission lines	Length (km)
TL 525kV Gravatai - Capivari do Sul	70
TL 525kV Povo Novo - Guaiba 3 C2 E C3	2 x 246
TL 525kV Santa Vitoria do Palmar - Marmeleiro C2	52
TL 525kV Marmeleiro - Povo Novo C2	152
TL 525kV Candiota - Guaiba 3 CD	2 X 272
TL 525kV Guaiba3 - Nova Santa Rita	40
TL 525kV Guaiba 3 - Capivari do Sul	174
TL 525kV Guaiba 3 - Gravatai	116
TL 525kV Capivari do Sul - Sideropolis 2	249
TL 230kV Viamão 3 - Capivari do Sul	60
TL 230kV Guaiba3 - Nova Santa Rita	40
SS Capivari do Sul (1344MVA)	
SS Guaíba 3 (1344MVA)	-

5. BENEFITS OF THE PROPOSED EXPANSIONS

After this prospective study was published, in early 2013, more wind farms have been contracted in PPA Energy Auctions. The integration of these new projects is going to use almost all the existing transmission capacity before the installation of the proposed expansions.

As can be seen in Table 8 the transmission system capacity is expected to reach its limit by the year 2017, a year before the new transmission installations are going to be available. If no transmission expansion were made, two regions of the state would be unable to allow the integration of new wind farms to the grid.

Table 8 Contracted installed capacity and estimates on the system transmission capacity.

Region	Transmission Capacity in 2013 (MW)	Contracted Installed Capacity until 2017 (MW)	Remaining Transmission capacity available until 2017 (MW)	Expected Transmission Capacity in 2018 (MW)	Expected Transmission Capacity in 2023 (MW)
Coxilha de Santana	48	48	**0**	823	1662
Escudo Rio Grandense	22	0	22	1689	2476
Litoral Sul	250	250	**0**	1829	2876
Lagoa dos Patos	620	305	315	2096	3881

*No wind farms were contracted in Planalto das Missões or Serra Gaúcha regions.

It is also important to notice that the wind power potential in the Escudo Rio-Grandense region exceeds 700MW whether its transmission capacity is just about 20MW.

6. CONCLUSIONS

This paper has presented the results obtained by the prospective study developed by EPE focusing on the integration of future wind power potential in Rio Grande do Sul state. The future wind power potential that has been considered in the simulations was based on the information available for the registered projects that participated in the PPA Energy Auctions run by the Government from 2009 to 2012.

The proposed expansions will allow the integration of 9GW of wind power installed capacity by 2023, and the results of this study will serve as major guidelines for defining future transmission installations and the wind farms integration.

After the installation of all proposed grid reinforcements, the connection to the grid is not going to be limiting factor anymore. However, EPE has to be constantly monitoring the results of the PPA Auctions in order to foresee any possible future transmission restrictions. Whenever a transmission restriction is found, new prospective studies shall be made.

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